A collaborative working paper by the Hydro Empowerment Network[[1]](#footnote-1)

Frequently Asked Questions

Grid Interconnection of Micro and Mini Hydropower Plants

Below are answers to frequently asked questions relevant to stakeholders of micro and mini hydropower, including government, utilities, developers, and communities, seeking to interconnect to the central grid. The paper refers to the situation where a micro hydropower plant (MHP) is originally built to supply electricity to a local mini-grid. Once the national grid arrives, the MHP can feed either all produced electricity to the national grid, or only excess electricity that remains after providing to consumers connected to the mini-grid. This means that consumers that are connected to the mini-grid can continue to receive electricity from the MHP system, and they can also partially or fully be supplied by the national grid.

# Why is interconnection of Micro and Mini Hydropower required?

Due to a lack of productive use of energy, often off-grid MHPs operate at very low plant factor, on an average less than 30%, resulting in sub-optimal utilization of resources.

Foremost, grid interconnection of a MHP **allows increasing its plant factor and thus generating additional revenue**, since the total number of sold kWh’s from the mini-grid increases. If the feed-in tariff is higher than what the local consumers paid, then the benefit for the MHP is even higher. Both aspects can help to increase revenues and therefore help to ensure long-term sustainability of the MHP. In some community-owned grid interconnected projects, the revenue is used for village social welfare activities, e.g. salaries of school teachers, funeral costs, and health clinics.

Secondly, grid interconnection allows **consumers in the local mini-grid** to receive power from the utility when the MHP is not producing sufficient power to meet the local demand. Insufficient power is a common reality in MHP villages where the number of households and/or appliances has increased, or the water flow has decreased over time.

Furthermore, from the point of view of the **national utility**, the interconnection will help to decrease the dependability of the distribution network on a very few centralized points of supply. Thus the grid integration of distributed generation helps to decrease transmission and distribution losses.

Moreover, it helps improve robustness of the local mini-grid thus supporting industrial consumers (particularly induction motors), and contributing to the local economy. The consumption of electricity by productive end use has much higher economic rates of return.

# What are possible business models for grid interconnection?

There are different options for grid interconnection when the national grid reaches the mini-grid, depending on the negotiations between the MHP developer, the utility, and the MHP consumers. In general, the MHP developer can become one of the following.

**Business Model A: Pure power producer.** The MHP becomes a Small Power Producer (SPP), selling all of its generation to the utility. The original consumers of the MHP become customers of the national utility. In case of power outage in the utility grid, the MHP can no longer supply the village / mini-grid separately.

**Business Model B: Pure power distributor.** Electricity is purchased at wholesale from the utility, and the mini-grid is used to distribute at retail to consumers. In this case the MHP generation is abandoned.

**Business Models C-1 and C-2: Combined power producer and power distributor.**

*Model C-1. Without Isolation Mode Option*

The MHP sells all of its generation to the utility and the village purchases electricity at wholesale from the utility to distribute to the original mini-grid consumers. For the utility, this means that collection of tariff will be regular and more convenient, since the utility will not need to collect tariff from individual customers. However, in case of power outage in the utility grid, the MHP will not be able to function in isolated mode to supply its generation to mini-grid consumers.

*Model C-2. With Isolation Mode Option*

The MHP sells all of its generation to the utility and the village purchases electricity at wholesale from the utility to distribute to the original mini-grid consumers. For the utility, this means that collection of tariff will be regular and more convenient, since the utility will not need to collect tariff from individual customers. However, in case of power outage in the utility grid, the MHP will not be able to function in isolated mode to supply its generation to mini-grid consumers.

The MHP can sell its generation to the utility *or* to the mini-grid, made possible by the option for the MHP and the mini-grid to run in isolation mode. In the case of power outage in the utility grid, this configuration allows the MHP to supply to the mini-grid. It also allows the generation from the MHP to first meet the demand of the mini-grid customers; if there is excess remaining, it can be sold to the utility. The consumers would pay the monthly tariff to the MHP owner for the total energy consumed --both during grid-available and grid-outage periods (the latter being when the MHP is supplying electricity to the same consumers in isolated mode). The tariff paid by consumers will be pre-negotiated and set by the MHP owner.

The MHP would receive/pay the money from/to the grid according to the reading in the net-meter placed in the utility line. The MHP is thus a local distribution licensee where such licenses are required. The distribution tariff may be under the oversight of the Regulatory Commission once it is grid connected.

Table 1.Schematic for Business Models A, B, and C.

|  |  |
| --- | --- |
| **Business Model A** | **Business Model B** |
| **Business Model C-1** | **Business Model C-2** |

# What are options for synchronizing the MHP with the central grid?

There could be various options for Point of Common Coupling (PCC) for MHP and central grid. Technically feasible models for synchronization of MHPs with central grid include the following.

**Synchronization Model I.** In this model synchronization is done at the MHP generator bus voltage with an *Air Circuit Breaker (ACB)* or a *High Current Contactor (HCC).* This model is suitable for *Business Models A and C-1* above. For *Business Model C-2*, it is optional, but desirable to reduce downtime in case of plant-shutdown and recovery.

**Synchronization Model II.** In this model synchronization is done at the voltage of the Local Grid (network voltage), e.g. 400 V, 11 kV, 33 kV or similar medium voltage (MV) with circuit breakers of this voltage. This is required if the MHP capacity exceeds a specified capacity as per the regulation or notification of the Grid Owner. In Nepal, it is recommended that above 40 kW size, a MHP should have its own transformer to connect to the 11/33 kV network directly. Even then a breaker at 11 kV may be avoided if the ACB is employed at the low voltage (LV) side of the transformer for economic reasons. However, some grid owners insist on having a circuit breaker at the 11 kV side, which usually makes grid interconnection of small MHPs smaller than 100kW financially not viable. In case of *Business Model C-2*, when there is mini-grid synchronizing point with a *Vacuum Circuit Breaker (VCB) at* the point of delivery to the utility grid, then a MV circuit breaker at the transformer is not necessary in any case and can be substituted by a high voltage (HV) fuse or drop-out fuse link.

**Synchronization Model III**. In this model synchronization is at the mini-grid interconnection point -- at the tie-line with the VCB and synchro-check relays. This is required for *Business Model C-2*, where the local distribution and energy metering is the responsibility of the MHP. The mini-grid synchronizing point should have a VCB, as well as two Potential Transformers (PTs) on each side of the connecting point, and appropriate devices to protect wrong closure of circuit. The control cubicle, a metal enclosed switchgear, normally also houses control devices for remote close and open of the circuit breaker, protective relaying and energy meters.

# What is the best suitable interconnection voltage?

Based upon the inter-connection model, for *Synchronization Model I*, the interconnection voltage is the same as the generation voltage of 400 V or 3300 V or as the case may be.

The step-up voltage for inter-connection depends upon the voltage level used for local distribution. For large area distribution (by micro hydro standards), the local distribution voltage may be 11 kV. If the generation capacity or the load of the local network is high, i.e. in the range of more than 5 MW, then the interconnection voltage may be higher.

The interconnection voltage level also depends upon what voltage level is available at the nearest grid substation. If only 33 kV is available, then stepping up to 33 kV for interconnection would be necessary.

The voltage level also depends upon the power that may be transported during local off-peak time when most of the power locally generated has to be supplied to the national grid. The phase imbalance and voltage fluctuation are higher in a 400 V system compared to an 11 kV system. Thus, the preferred voltage level for interconnection of micro hydro is 11 kV. However, an MHP with a capacity lower than 40 kW can be connected at a 400 V system which would be appropriate as the cost of interconnection would be lower.

Net metering policies are in the process of notification in Nepal. It is recommended to allow connection at local distribution voltage of 400 V up to a capacity of 40 kW MHP provided the distribution transformer connected is of 100 kVA or higher capacity. In other cases, it is recommended to have a separate transformer of 11/0.4 kV or 33/0.4 kV type.

In many cases, where the distribution transformer LV side is star connected with grounded neutral, and the generator also has a grounded neutral, it is always recommended to employ a delta-star transformer to connect to the local grid even if the MHP size is smaller than 40 kW.

For larger MHPs, the selection of voltage is mostly determined by the voltage level available from the nearest substation whether it is 11 kV or 33 kV.

# Will islanding be a problem?

*No,* the intentional or unintentional islanding can be detected by a Loss of Mains (LoM) Relay.

Islanding may be intentionally desirable when the MHP is remotely located and the Grid connecting lines are very long resulting in frequent tripping. In such cases, measures to operate independently in an island mode are desirable for local users. It has to be ensured that a proper island detection mode is available, and that circuit breakers open and close to prevent wrong synchronization.

It is also desirable that such nodes of mini-grid synchronization have a communication facility with the local substation to ensure safe operation during grid problems.

# Is there any concern over human safety during maintenance of the utility line due to interconnection of MHP?

*No,* there will not be any possibility of back feed in case of a de-energized utility line. Whenever there is grid outage, instantly LoM relay helps to isolate the MHP from the utility line. It is desirable to install a device which isolates and grounds the line, thus avoiding any inadvertent switching of HV during maintenance in the line.

# Are both induction and synchronous generators suitable for grid interconnection?

*Yes,* but it is desirable that in a cluster of MHPs, connecting in remote areas far away from the substation, there is a combination of synchronous and induction generators to balance the reactive power demand and to avoid drawing it from grid and thus increasing system loss.

# Can the MHP generator supply reactive power while the utility has more demand of reactive power?

*Yes.* A synchronous generator can be operated safely within the operating region of its power diagram, which means the generator can absorb or supply reactive power as the node voltage varies with the load condition of the grid. It is however required that the excitation system of the MHP shall have that capability to support voltage within the ceilings of its capacity.

# What will be the tentative cost of interconnection?

It varies from country to country and also depends on the interconnection voltage levels. In Nepal, the prevailing interconnection cost at 400 V will be approximately USD 10,000 with requirement for a separate transformer but without circuit breaker at HV side. The cost depends upon the instrumentation and switchgear mandated by the grid owner. Technically, the costs can be economized for small MHPs.

At the LV level synchronization without transformer, the costs can be less than USD 4,000.

The cost tends to approximately USD 25,000 when the circuit breakers and HV PT and current transformer (CT) are required at the HV side along with transformer. Normally, these costs depend upon the synchronization voltage level rather than the capacity of the MHP connected.

# Up to what capacity is MHP financially viable for interconnection?

It depends on the cost of interconnection and the tariff fixed in the Power Purchase Agreement (PPA). In Nepal, MHPs above 25 kW installed capacity generally have positive financial return, considering no investment is required for upgrading MHP. For induction generators, if the grid owner allows connecting using high current contactors for induction generators at capacities below 25 kW, then it can be financially viable at lower capacities till 5 kVA 3-phase generators.

Generally, below 25 kW, it is the length of the line required to connect to the grid that determines the viability. It is normal practice that even when an induction or synchronous generator is allowed to connect at 400 V, it is not at the node near the MHP plant but at the immediate LV at the end of the transformer. This means that usually the distribution transformer is located at a distance from the MHP requiring a separate 400V cable or ACSR conductor line to be installed. The viability thus depends upon the length of such lines. For 20 kW induction generators, generally such lines should not be more than 1 km in length.

The local distribution network may be so designed that the distribution transformer is located nearer to the MHP to enable its interconnection utilizing its active power support.

For MHP larger than 100 kW, 11 kV line up to 5 km may be viable. The fact to be noted here is that costs of such lines increase significantly without road accessibility.

# Is there a guide to selecting the interconnection voltage level based on the available distance?

Within the feasible radius of interconnection area, the voltage level is already dictated by the network. However, the synchronization point may be optional depending upon size of the generator, as explained above.

For generators sizes larger than 100kW, the selection of the voltage or the conductor can be optimized based on the capital costs and the capitalized cost of the losses in the line.

Most economical voltage level for Transmitting Power can be determined using this formula, *kV=5.5\*sqrt((L/1.6)+(kW/150))* where *L* is the length of line in km between plant and point of interconnection , and *kW* is the three phase power to be transmitted.

# Will there be problem with utility feeder line protection coordination?

At the point of synchronization, the MHP is required to install an island detection relay, a synchro-check relay (IEC device No. 25) and a switchgear capable of breaking small short circuit currents (~ 630 A at 400 V). With these the utility should not have line protection concerns.

At capacities larger than 100 kW, the substation where the line feeder originates from shall be required to have separate protection settings for reverse current.

The over-current settings radially towards the MHP may be affected by such MHP if there are sequential substations with protective relaying based on over-current settings. Normally this is not the case. Hence, an overcurrent setting at the MHP for the generator protection should be sensitive enough to off-set any effect on the substation protection settings.

As shown in the figure below, there may be chances of false tripping of the healthy feeder due to presence of MHP generator when relay settings are not precisely coordinated. Normally the faulty feeder that carries the sum of the fault current from grid transformer as well as the MHP would trip first due to the inverse time characteristics, and separating the fault from the rest of the grid. However this false trip can be prevented by precise coordination of the protection settings, or with the following options.

*Option (i).* Change the fault clearing time of the existing relay of the MHP carrying feeder. *Option (ii).* Increase the pick-up current setting of the MHP carrying feeder.

*Option (iii).* Change the O/C relay to directional O/C relay of the MHP carrying feeder and allow the reverse current to be slightly higher than forward current.

In Options (i) and (ii), the increase of the pick-up current or the time setting leads to less sensitive feeder protection. In Option (iii), the directional over-current (O/C) relay is an expensive solution and usually not used for feeder protection.

All of above options may be considered when the grid transformer, as shown in Fig. 1, is of a small size and similar to the MHP size. In cases where the grid transformer at the substation is at least 5 times larger than the MHP, the participation of the MHP during the transient phase of the line-fault will not cause such disturbances, and therefore its effect can be neglected. This means there will not be any need of special protection coordination.



Figure 1. Mismatch of feeder line protection coordination due to interconnection of MHP.

## List of Abbreviations

ACB Air Circuit Breaker

CT Current Transformer

HCC High Current Contactor

HV High Voltage

LoM Loss of Mains

LV Low Voltage

MV Medium Voltage

MHP Micro hydropower plant

O/C Over current

PCC Point of Common Coupling

PT Potential Transformer

SPP Small Power Producer

USD United States of America Dollar

VCB Vacuum Circuit Breaker

## Contributors

Hitendra Dev Shakya, Nepal Electricity Authority (NEP)

Ram Prasad Dhital, Alternative Energy Promotion Centre (AEPC)

Satish Gautam, UNDP Renewable Energy for Rural Livelihoods (UNDP-RERL)

Sanjay Kumar Sharma, Independent Consultant

Jiwan Kumar Mallik, UNDP Renewable Energy for Rural Livelihoods (UNDP-RERL)

Hedi Feibel, Swiss Resource Centre and Consultancies for Development (Skat)

Dipti Vaghela, Hydro Empowerment Network (HPNET)

1. The [Hydro Empowerment Network](http://www.hpnet.org) (HPNET) is knowledge exchange and advocacy platform for micro and mini hydropower in South and Southeast Asia. This knowledge product was coordinated by HPNET member [Jiwan Kumar Mallik](https://www.linkedin.com/in/jiwan-kumar-mallik-32713726/?ppe=1) at the [UNDP-Renewable Energy for Rural Livelihoods (RERL)](http://www.np.undp.org/content/nepal/en/home/operations/projects/environment_and_energy/rerl/home.html) project at [Alternative Energy Promotion Centre](http://www.aepc.gov.np/). For more information, contact us at [hydroempowerment@gmail.com](mailto:hydroempowerment@gmail.com) or [jiwan.mallik@aepc.gov.np](mailto:jiwan.mallik@aepc.gov.np). [↑](#footnote-ref-1)